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Research and Development Technical Report
ECOM-3582



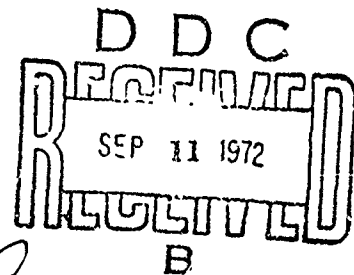
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ERBIUM LASER RANGEFINDING

Jack M. Strok
William C. Beattie
Edith J. Tebo

June 1972

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1. ORIGINATING ACTIVITY (Corporate author) US Army Electronics Command Fort Monmouth, N. J. 07703		2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	
		2b. GROUP	
3. REPORT TITLE ERBIUM LASER RANGEFINDING			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Technical Report			
5. AUTHOR(S) (First name, middle initial, last name) Jack M. Strok William C. Beattie Edith J. Tebo			
6. REPORT DATE June 1972		7a. TOTAL NO. OF PAGES 11	7b. NO. OF REFS 0
8a. CONTRACT OR GRANT NO.		9a. ORIGINATOR'S REPORT NUMBER(S) ECOM-3582	
b. PROJECT NO. LS6 62703 A 186			
c. Task No. -C1		9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d. Work Unit No. -031			
10. DISTRIBUTION STATEMENT Approved for public release; distribution unlimited.			
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY US Army Electronics Command ATTN: AMSEL-CT-L Fort Monmouth, N.J. 07703	
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UNCLASSIFIED
Security Classification

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Reports Control Symbol OSD-1366

Technical Report ECOM-3582

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DA Work Unit 1S6 62703 A186 04 034

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ABSTRACT

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ERBIUM LASER RANGEFINDING

1. INTRODUCTION

a. Laser equipments currently being developed for the military present a serious eye hazard at ranges up to several kilometers. Concern over this potential eye hazard for laser systems operating in the visible and near infrared has resulted in the search for satisfactory lasing materials in the infrared region beyond $1.3\text{ }\mu\text{m}$. Measurements by W. J. Geeraets, Medical College of Virginia, have shown that the retinal and choroidal absorption in the human eye is negligible at these wavelengths. Possible laser sources for such wavelengths include erbium in various hosts, parametric oscillators as down-converters for neodymium, Raman-shifted neodymium, holmium and dye lasers. With the advent of many rangefinders and designators in the FEBA, the potential of causing damage to human eyes with ruby or neodymium lasers is considerable.

b. In June 1968 a program was initiated to develop a laser transmitter head using erbium doped glass and erbium:YAG. Attempts to develop the proper pump pulse required a completely new approach due to the apparent need to shape the pulse and the general requirement to use a critically damped pulse. Optimization of the pulse was a difficult task to perform experimentally. The key parameters involved were the number of LC sections desired to shape the pulse, voltage range, and the LC combination to provide the desired pulse length. The first approach to this problem was to determine the fluorescence time of the material used. This was found to vary from 12 to 14 milliseconds for erbium in silicate glass, from 8 to 11 milliseconds for erbium in phosphate glass, and from 5 to 10 milliseconds in erbium:YAG.

c. It was felt that the ideal pump pulse should have its trailing edge pass through the peak fluorescence of the material being used. From the fluorescence measurements, this called for a pump pulse with a 3 to 4 millisecond length. The L and C values chosen were 1.1 millihenries and 1000 microfarads, respectively, with a voltage range from 300 to 800. The pulse width would change as different voltages in the above range were applied. The pulse width under these conditions varied from 2.5 milliseconds to 3.5 milliseconds.

d. The first erbium doped "rod" tried was a rectangular piece $1/8'' \times 1/2'' \times 3''$ long in a silicon glass base material. This "rod" was then placed in a tightly wrapped aluminum foil cavity using a 100% rear reflector and a 95% front reflector. Lasing action took place at 800 joules; the energy output was not measured. A pyrex sleeve for UV protection was placed around the rod before conducting further tests. After about 20 firings, wherein the output fell off after each firing, the sample was removed from the cavity and examined. Considerable solarization had taken place. A uranium glass sleeve was also tried; however solarization was still present at this 800 joule level. An Owens-Illinois rod was then tried. Lasing action did not occur up to 800 joules input. The front dielectric was raised to 90% and the

pump pulse width was increased to 4 milliseconds by going to a ten section network. Lasing action did occur at 500 joules input. After about 20 firings, the rod was removed from the cavity and examined. There was noticeable crazing along the length of the rod.

e. Two used silicate glass rods received from the Electronic Components Lab allowed further testing of erbium materials. These rods were from a contract with American Optical Corp and the sizes varied due to refinishing after test damage occurred at the EC Lab. Some experiments were performed to determine threshold and output energy as a function of various pulse lengths. One of the best combinations produced a threshold of 350 joules with an output of 28 millijoules for 500 joules input.

f. Although these results were far from encouraging, preliminary atmospheric measurements by Dr. Rufus Bruce of the Atmospheric Sciences Laboratory at White Sands indicated that the erbium wavelength region was still an excellent region in which to attempt to find a suitable laser.

g. Concurrent with these tests, various tests were also being conducted on the then available photodetectors at this wavelength. Several commercially available detectors, all of which used germanium as an active material, were tested. In March 1969, a memorandum report was prepared discussing the four detectors tested: A Philco LL4520; an ENL 653 photodiode; a TI PEX 5001 avalanche detector constructed for operation at 1.06 microns; and a TI 1.54 micron detector, constructed similar to the PEX 5001 but without avalanche gain. Of these, the Philco and the avalanche TI provided the best performance but the Philco photodetector offered the best chance of meeting field requirements because the power requirements of the TI device were quite large (1 watt for a thermoelectric cooler, 6 volts and 60 volts for the transistor amplifier supply and avalanche bias, respectively).

h. In June 1969, two erbium silicate glass rods were received from American Optical Corp. Rod size was $\frac{1}{2}$ " x 3" and had frosted sides. A pulse forming network of ten sections with a total LC of 1 millihenry and 1000 microfarads was used. A rear dielectric of 100% reflectivity and front dielectric of 99% reflectivity were used. The threshold for this system was 150 joules. Dry nitrogen flowing through an open ended cavity was used as a coolant. Pump pulse was reduced to a six section network; a 2.5 millisecond pump length was used. Threshold for this combination was 165 joules. This shorter pulse raised the threshold about 10%.

i. Q-switching indicated that a field system would be practical if the pump pulse could be shortened to the point where an acceptable power supply weight could be realized. Although this did not seem to be too promising, it was felt that considerably more studies should be made of divers concentrations of erbium and other dopants (ytterbium and cesium) in various hosts.

j. In June 1969, a contract was placed with Martin Marietta Orlando for an erbium transmitter module and the efforts to develop an erbium rangefinder were cooperatively attacked.

k. In July 1969, a 1/8" x 3" glass clad rod was received from Dr. Woodcock of American Optical Corp on a loan basis. At that time, it was felt a 4 millisecond pump pulse would be used. With this longer pulse, the capacitance is higher. However, the voltage can be lowered eliminating some of the solarization problems encountered during the first tests. Parameters were selected for the cavity design, Q-switch assembly, and cavity length that would be near optimum for field system applications rather than for the production of the lowest possible threshold. The cavity was a split glass tube silvered on the outside walls with an inner diameter of 3/4"; the front reflectance was 80%; the cavity length was 9" with external mirrors coated for 1.5 microns. This 1/8" x 3" rod had a non-Q-switched threshold of 85 - 90 joules when high reflectivity mirrors were used. The Q-switched threshold was around 150 joules using the 80% dielectric mirror. The rod was checked in the Q-switched mode at three different joule inputs. The 250 joule level produced 1.1 megawatts with a 40×10^{-9} second pulse width. The 300 joule level yielded 1.5 megawatts with a 40×10^{-9} second pulse width. The 384 joule level emitted a 1.74 megawatt pulse with the same pulse width. This rod was returned to Dr. Woodcock with the information obtained.

1. A detailed description of the most recent research follows.

2. APPARATUS

a. Laser Transmitter. The laser rod used in these ranging experiments was supplied by American Optical Corporation. Overall dimensions were .235" diameter x 3" long. The active material, a 3 mm diameter core of erbium in glass, was clad in silicate glass for UV protection. Optical pumping of the rod was accomplished with a cylindrical xenon flash lamp whose bore dimensions were 4 mm inner diameter x 6 mm outer diameter. Arc length for optimum coupling to the laser rod was 2.65 inches. Both the rod and flash lamp were housed in a reflecting cavity, ventilated with dry nitrogen.

(1) Flash lamp power was delivered by eight 100 μ F capacitors and eight 100 μ H inductors in a network designed to provide 200 - 400 joules in a 2.5 ms pulse. A schematic of the pulse forming network (PFN) is given in Figure 1. An enhanced scope trace of a somewhat longer pump pulse is given in Figure 2. It was produced from an earlier PFN composed of ten 100 μ F capacitors and ten 100 μ H inductors. Vertical deflection came from the output of a Philco-Ford L4520 detector looking into the open-ended laser cavity. The spikes at 2.5 ms were due to laser light.

(2) Two mirrors on the laser rod axis spaced 12 inches apart formed the interferometer. (See Figure 1.) The partially transmitting mirrors were glass flats coated with a dielectric film which possessed a reflectivity maximum at 1.54 μ . Q-switching was performed by rotating the rear mirror at 24,000 r/min and synchronizing mirror position with flash lamp firing by means of a magnetic pickup. The 24,000 r/min synchronous motor was a Globe Industries Model 53A109.

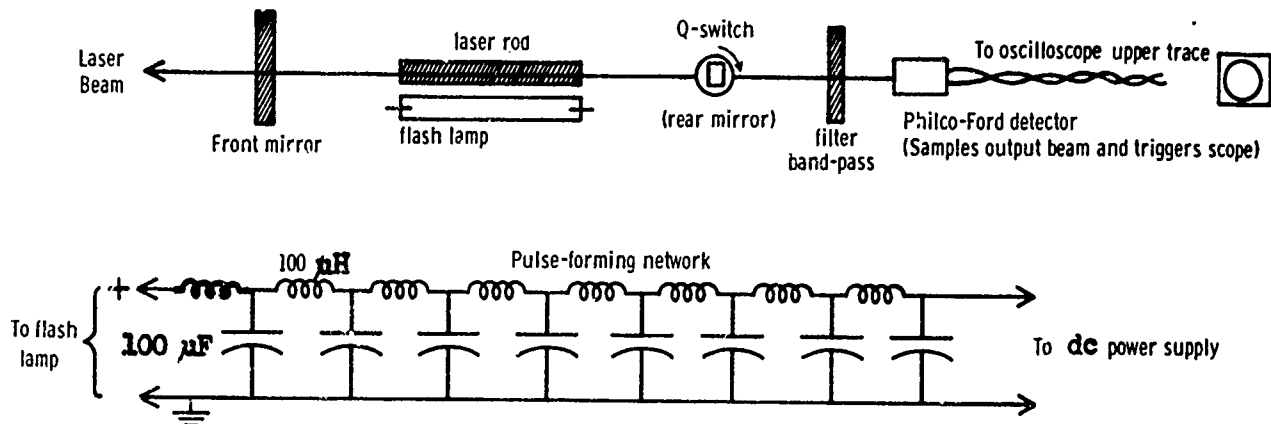
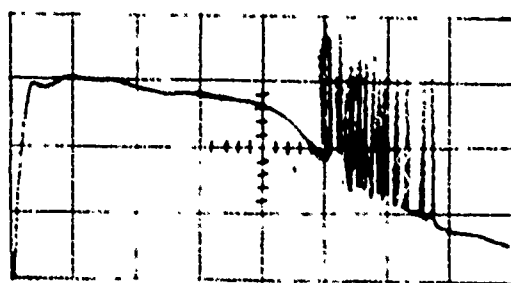


Figure 1. Transmitter Sketch



Time base: .5 ns/cm.
PFN energy: 180 Joules

Figure 2. Flashlamp Output in Time

(3) The complete laser transmitter, assembled by Martin Marietta Corp with technical support from W. Beattie, Laser Techniques Team, produced output pulses at 1.54μ of roughly 30 millijoules energy, 35 nanosecond duration, and 3 - 4 milliradian divergence. Total weight was approximately 40 lb.

b. Laser Receiver. A 12" focal length Cassegrainian telescope was used to focus return pulses from reflective targets on the sensitive area of a Texas Instruments APD-1.54 germanium avalanche photodetector module. Module signal outputs were amplified with an AMF Cybertran VI-40-10M-50 instrumentation amplifier and displayed on a Tektronix model 555 oscilloscope. (See diagram in Figure 3.) A complete description of the APD-1.54 may be found in the Texas Instruments pamphlet "Description and Operating Instructions for APD-1.06 and APD-1.54 Germanium Avalanche Photodetector Module."

3. ALIGNMENT PROCEDURE. Both receiver and transmitter were mounted on a common baseplate. (See Figure 4.) Receiver positioning was fixed relative to the baseplate, however, the transmitter mounting had independent adjustments for azimuth and elevation. The transmitter and receiver were aligned to an identical target with the aid of a strip of reflector material, an Image Optics pulsed 1.06μ laser, and a Spectra-Physics model 130B helium-neon laser as follows:

a. Receiver Alignment. The 1.06μ pulsed laser was adjusted to illuminate the reflector strip at a downrange distance of 1000 meters. (Accurate aiming of the pulsed laser resulted in observing bright flashes on the reflector strip with a Varo, Inc. model 5500c infrared viewer.) Then the receiver-transmitter baseplate was positioned to obtain maximum reception of the return pulses. Final adjustment of the receiver involved using detector module micropositioners to exactly focus the return pulses on the APD-1.54 detector surface (.01" diameter).

b. Transmitter Alignment. After the above receiver alignment, the erbium transmitter was aimed at the same reflector target by using the coaxial front and rear output beams of the He-Ne laser. The front He-Ne beam was adjusted to illuminate the downrange reflector (accurate aiming resulted in a red reflection). Then the erbium transmitter positioners were adjusted until the rear He-Ne beam entered the laser rod at normal incidence. This procedure completed system alignment at a distance of 1000 meters.

c. Alignment to Other Targets. A telescope was mounted on the receiver-transmitter platform (see Figure 4) and adjusted so that the 1000 meter target was in the crosshairs. Ranging to other downrange targets at other distances was then possible by using the telescope as a sight. Minor adjustments of transmitter position to counter parallax were unnecessary when ranging beyond 1000 meters because of the transmitter beam divergence.

d. RANGING PROCEDURE. After sighting on a target of interest, the flash lamp pulse forming network was charged to a potential of 950 volts dc (360 joules energy) and discharged into the flash lamp. Laser beam sampling with a Philco-Ford IM520 detector initiated the sweep of a Tektronix model 555

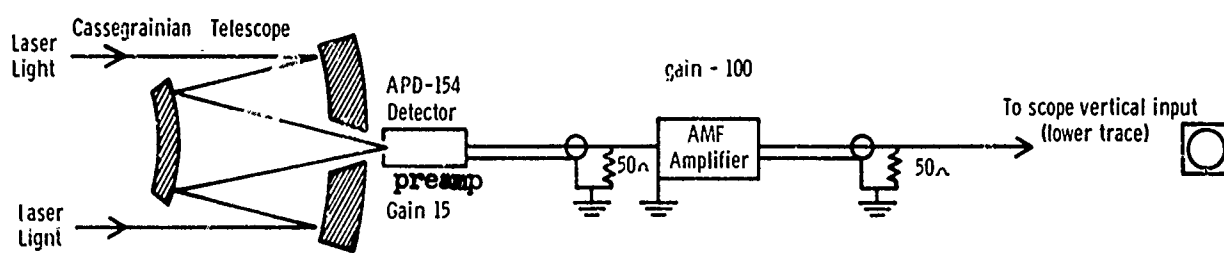


Figure 3. Receiver Sketch

dual beam oscilloscope while receiver output provided vertical trace deflection. Hence, target distance could be computed from return pulse position along the horizontal axis, the sweep rate, and the speed of light.

5. RESULTS

a. One target was a 2 x 2 meter square placed downrange a distance of 2635 meters. The square was painted white with a titanium dioxide paint. At 2635 meters, the laser beam spread to an approximately 9 meter diameter circle, so a considerable portion of the transmitter pulse was wasted. Reflection from all parts of the target contributed to signal reception because the APD-1.54 sensitive area was .25 x .25 mm and a simple calculation showed that the focused image of the target on the APD-1.54 detector surface was approximately .2 x .2 mm.

b. Figure 5 is typical of data obtained during ranging. The horizontal scale is 750 m/cm. The .7 volt pulse at approximately 3.5 cm came from the 2635 meter target. Later pulses, around 4.2 cm, were reflections from tree line behind the 2 x 2 meter target. These trees were approximately 3200 meters from the rangefinder. For the 2635 meter target, the signal to noise ratio was approximately 25.

c. Another target used was a white 4 x 4 meter square at a distance of 1050 meters. This target subtended the entire laser beam, although its .5 x .5 mm focused image was 4 times larger than the sensitive area of the detector. Figure 6 shows the prominent return pulse. The horizontal scale is 300 m/cm. Again, the signal to noise ratio was approximately 25.

6. NOISE. A Ballantine Model 323 rms voltmeter was used to measure receiver noise. The noise had origins in the detector module, the Texas Instruments preamplifier, and the AMF amplifier. At room temperature, the AMF amplifier was found to contribute 2.5 mV noise; the TI preamplifier, 7 mV noise; and the detector, .5 mV noise (measured in darkness with no cooler voltage applied). It was discovered that normal room lighting and/or cooling of the detector did not affect these rms readings. Detector cooling is required only in high ambient temperature situations.

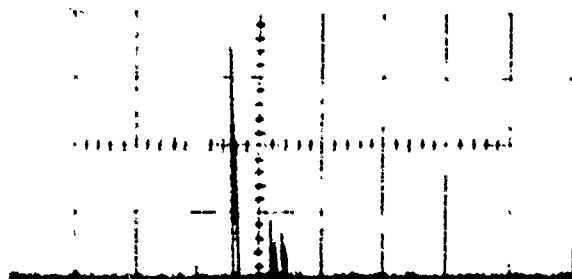
7. ATMOSPHERIC ATTENUATION

a. The transmittance of the atmosphere at a particular wavelength over a horizontal path may be expressed as:

$$T = \exp(-\sigma R) \text{ where } \sigma = \text{Attenuation Coefficient}$$

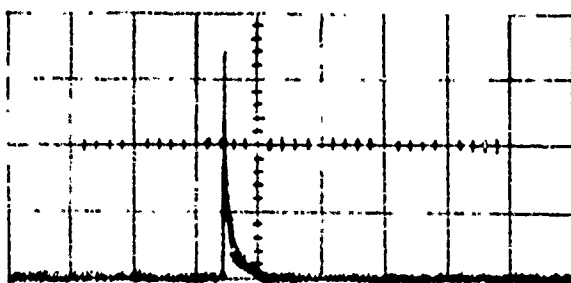
$$R = \text{Path Length}$$

On page 7 - 8 of the RCA Electro-Optics Handbook, a family of curves of σ vs wavelength for various atmospheric conditions was found which indicated that



Time base: $5 \mu\text{s}/\text{cm}$ (750 m/cm)
 Vertical Sensitivity: $.2 \text{ V}/\text{cm}$

Figure 5. Ranging Results (2635 Meter Target)



Time base: $2 \mu\text{s}/\text{cm}$ (300 m/cm)
 Vertical Sensitivity: $.2 \text{ V}/\text{cm}$

Figure 6. Ranging Results (1050 Meter Target)

at 1.54μ in clear air, σ was approximately $.15 \text{ km}^{-1}$. Use of this value of σ in the above transmittance equation yielded the following values of T for the rangings described above:

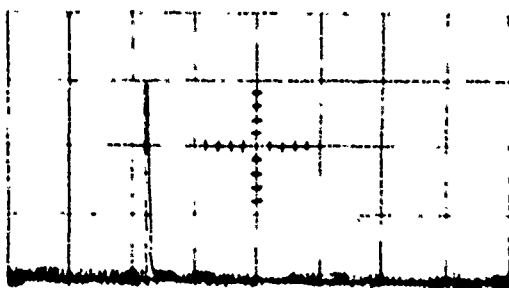
$$T = .45 \text{ for } R = 2 \times (2.635) \text{ km (far target)}$$

$$T = .73 \text{ for } R = 2 \times (1.050) \text{ km (near target)}$$

Taking into account transmitter beam divergence and atmospheric attenuation, signal returns from a 2×2 meter target would become indistinguishable from detector noise when the target reached a distance of approximately 6 km. This defines an approximate upper limit to the ranging which may be done with the present system to reasonably sized targets.

b. The traces in Figures 7 and 8 are presented as an example of how atmospheric conditions can influence laser ranging. They show return pulses from a white 4×4 meter target 1815 meters downrange under both clear conditions and heavy falling snow. These photographs were taken within 15 minutes of each other with identical receiver sensitivity and transmitter input power. Through scattering and absorption over the range path, the falling snow decreased return pulse amplitude by approximately $2/3$.

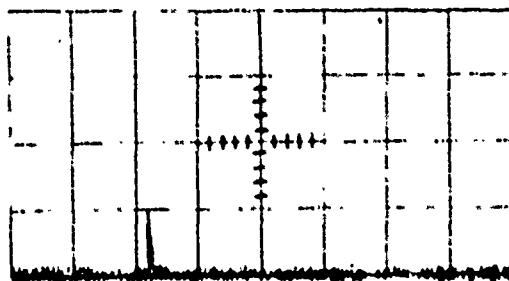
8. CONCLUSIONS. Ranging to several kilometers has been shown feasible with the present system. In fact, a laser beam collimator might be used to extend the measurements even further. Due to the requirement of a $2\frac{1}{2}$ ms flash pulse, the pulse forming network and power supply were necessarily weighty and not compatible to man-portability. It was, therefore, the feeling of the authors that a Raman shifted neodymium laser be investigated as a lightweight alternative to the erbium laser.



Vertical sensitivity: .2 V/cm.

Figure 7. Return Pulse Obtained Under Clear Atmospheric Conditions

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Vertical sensitivity: .2 V/cm.

Figure 8. Return Pulse Obtained Under Heavy Snowfall